HORIZONTAL SYSTEM-OF-SYSTEMS INTEGRATION VIA COMMONALITY

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ABSTRACT

A requirement for the Army's Future Force Unit of Action is equivalent (or identical) functionality across operational systems, remote operations, modeling, simulation, training, rehearsal, etc. This requirement necessitates tightly-coupled systems integration via commonality of the low-level functions across these modes of use. This pathfinder project identifies such commonality via a typical functional decomposition for a representative integrated process, which also has commonality with existing Army simulation models. An understanding and use of such commonality will facilitate the system-of-systems integration. The resultant enhancements will assure joint inter-operability; will enable networked battle command, lethality, and training; will improve reliability, survivability, and efficiency; will ease the effort for maintenance and improvements; and will reduce the life-cycle cost.

1. INTRODUCTION

The U.S. Army's Future Force Unit of Action is an implementation of 21st century technology to address the challenges of modern war-fighting via a lightly armored, highly mobile, self-sustaining force. The Unit of Action achieves superiority across the full spectrum of missions through a distributed, tightly coupled system of systems, including current forces, new offensive systems, and complementary systems. The Unit-of-Action, current, and legacy systems are linked (and perform in highly automated ways) via a distributed, secure, ubiquitous, mobile *ad hoc* communications network. This combination of information technology and Unit-of-Action performance creates a unique set of conditions, by which a revolutionary concept of a system of systems can be implemented. The combination of advanced weapons systems, performance requirements, and information technology (both hardware and software) enables a new paradigm of: "see first, understand first, act first, and finish decisively."

The underlying information technology has four components: accurate and timely data gathering via intelligence, surveillance and reconnaissance (ISR) by appropriate sensors; high-speed networks for information transfer; high-performance computers on the battlefield and elsewhere to process the information; and highly trained soldiers with advanced weapons [(un)manned, air/ground vehicles, weapon systems, and their respective munitions] to control the situation and engage the adversary. Tightly-coupled integration of these systems is essential for action and decision-making via C4ISR: command and control (C2), communications, computers, and ISR. However, the system-of-systems concept is new and unproven. Moreover, tight integration is precedent setting, because the underlying methods are so new or not yet developed.

The project goals are: (1) to identify commonality examples among the systems of the unit of action, (2) to understand commonality, and (3) to determine commonality implications for follow-on work. Our sponsor and proponent is Kent Brookins [Director of the Army's Simulation and Modeling for Acquisition, Requirements and Training (SMART) office]. A crucial aspect of this work is interaction with the Lead Systems Integrator to identify and understand commonality of the complex Unit-of-Action system of systems. This approach has three benefits: (1) recognizing overlap among simulations, models, and operational systems to improve development; (2) software re-use to reduce development costs; and (3) understanding of system-of-systems integration, in terms of data and algorithms.

3. METHODOLOGY

Our FY04 work includes: (1) functional decomposition (FD) of a typical Unit-of-Action integrated process, involving well-defined steps for C2, communications, and sensors (including ISR); (2) correspondence between the FD from (1) to specific requirements from the Unit-of-Action Operational Requirements Document (ORD), and determination of any gaps; (3) characterization of representative Army model contributions and their correspondence to the FD from (1); and (4) determination of commonality across (1) - (3). We use the integrated process from (1) as an example and means, from which to develop a tractable and defensible commonality paradigm. The methodology is also scalable and testable for the entire Unit-of-Action domain at level-one fusion.

4. RESULTS

The main accomplishments to date are as follows: (1) choice and enhancement of a representative FD (hierarchical list of system functions) for Unit-of-Action planning, execution, assessment, and supporting use cases; (2) choice of the networked-fires (NF) as a

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representative integrated process; (3) definitions for commonality, interoperability, systems integration, function, etc.; (4) use of the FD from (1) to identify commonalities with the NF integrated process from (2) according to the definitions in (3) for C2, ISR, and communications. We find extensive commonality just within the NF integrated process. This understanding offers potential significance for software re-use, for coding efficiency, and for enhancement of system-of-systems integration; (5) discovery that the steps for NF are essentially identical to two other integrated processes: air defense and conduct cooperative engagement. (The latter process omits consultation of higher echelons for revenge and line-of-sight kills.) Thus, these results apply to three of the designated integrated processes (not one); (6) characterization of two current Army models (via primitive orders in CASTFOREM and via object-oriented class structure in OneSAF), which show commonality with NF; (7) typical matches between ORD requirements and the FD from (1); (8) determination that the FD for C2 is adequate for these purposes; (9) finding that the available FD for ISR and communications is inadequate for this work due to insufficient detail [e.g., collectData(SensorData) and process(SensorData) for all sensors and platforms; (10) examples of an adequate FD for ISR and for communications; and (11) collaboration with 32 working groups (roughly 100 people) in the Army and Lead Systems Integrator

5. IMPLICATIONS OF COMMONALITY

We find many instances of commonality between NF and the FD for components of C2, communications, and sensors. We represent this commonality via NF $\leftrightarrow$ FD. Analogous commonality exists between the NF and the primitive orders in the CASTFOREM Army model for C2, sensors, and communications. As before, we denote this commonality by NF $\leftrightarrow$ CASTFOREM. Similarly, we have found commonality between the Army model, OneSAF, and NF steps for C2, sensors, and communications, or NF $\leftrightarrow$ OneSAF. Finally, we have demonstrated the correspondence of specific ORD requirements (by number) and the NF steps, as denoted by ORD $\leftrightarrow$ NF. The transitivity property states that if A is equivalent to B (A $\leftrightarrow$ B), and B is equivalent to C (B $\leftrightarrow$ C), then A is equivalent to C (A $\leftrightarrow$ C). Thus, transitivity among these elements establishes commonality among all of them: ORD $\leftrightarrow$ NF $\leftrightarrow$ {FD, CASTFOREM, OneSAF}. This commonality is essential for tightly-coupled integration of the Unit-of-Action system of systems.

A second implication of commonality involves the time-serial progression of the discrete process steps through an integrated process (NF in the specific example here, and the steps for any integrated process in general). The standard approach to testing and evaluation (T&E),

and to verification and validation (V&V) of systems software is assessment of all possible missions, scenarios, and threads. The resultant number of possible combinations and permutations is immense and cannot be computed during any reasonable period of testing and evaluation. An alternative approach (to be evaluated in FY05-06) could potentially simplify this problem dramatically, and simultaneously make the computational problem tractable, as follows. All of the combinations and permutations for possible assessment include only the aggregate of all possible discrete integrated process steps, which are very finite and denumerable, as in the above examples. Moreover, the time-serial progression of any mission-scenario-thread involves specific state-to-state transitions among the discrete steps of each sequential integrated process, which are also finite and denumerable. One can therefore perform T&E as well as V&V by looking at the underlying functions (commonality) for each integrated process step. [We note that this approach should minimize interfaces between automatic functions (eliminate all of them if possible), because any interface implies non-interoperability between the components that are joined by the interface.] A successful outcome of the assessment assures the appropriate interoperability and data transfer for each state-to-state transition, thus easing T&E and V&V tremendously.

A third implication of this work is the quantification of the "chaos of war." We first denote each integrated process step with a unique state number (k) that has a range of $1 \leq k \leq K$, where the symbol (K) denotes the total number of steps across all of the integrated processes. One can then tabulate the number of instantiations (occurrences) of k-th state (r_k) during the time-serial progression of the Unit of Action through a total of N such states for a complete mission-scenario-thread sequence (i.e., the number of times that the functionality of the k-th state is invoked). One information measure is "Shannon entropy," $E = -\Sigma_k \rho_k \, ln\rho_k/(lnK)$, where $\rho_k = r_k/N$. The summation (Σ_k) occurs only over states with non-zero values of ρ_k. The symbol (ln) denotes the natural (base-e) logarithm. The denominator (lnK) assures that the value of E falls within the range, $0 \leq E \leq 1$. A value of $E=1$ corresponds to total chaos, while a value of $E=0$ corresponds to no chaos (complete determinism).

Early substantiation of the methodology can: provide guidance for coherent development; exploit the benefits of commonality; achieve more complete T&E and V&V at many times lower in cost; aid in spiral development; address system of systems integration finitely; and be readily transferred to the development staff.

6. ACKNOWLEDGMENT